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INTERIM REPORT ON NOVEL POROUS SHEET MATERIALS OF POTENTIAL SUITABILITY FOR MILITARY TEXTILE APPLICATIONS

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UNITED STATES ARMY
NATICK DEVELOPMENT CENTER
NATICK, MASSACHUSETTS 01760

U.S. ARMY MATERIEL COMMAND

Clothing, Equipment & Materials Engineering Laboratory

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Novel approaches to formation of porous sheets were considered as offering potential replacement, alternative or substitute materials for conventional textile applications. Some materials, processes and potential applications are suggested for further investigation.

Fibers, continuous and interrupted film, and foam were found to be the elementary structures which offer suitable performance features in general and

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20. govern the particular characteristics. Fibrous web systems continue to appear as the most favorable and versatile. The most economical routes to the formation of nonwoven fibrous webs are integral with the initial extrusion of thermoplastic polymers, as in the spunbonded, sprayspun, meltblown, fibrillated film and fibrillated foam processes.

There is growing potential for replacement of some woven and knitted fabrics with spunbonded, spunlaced, meltblown and stitchbonded webs.

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INTRODUCTION

During the 1950's and 1960's, considerable progress was made in developing alternatives to conventional woven and knitted fabrics made from preformed yarns. A new generation of nonwoven fabrics was made from chemically bonded staple (and paper) fibers in dry and wet processes. These were initially identified with disposable items and later became acceptable for more durable goods. Although these earlier materials were inexpensive, they had a limited textile market due to deficiencies in physical properties such as excessive stiffness, which accompanied increased bonding to achieve higher strength. Major industrial R&D efforts on other concepts and systems were eventually motivated by predictions of annual nonwovens sales approaching one billion dollars.

The 1970's are marked by a sudden acceleration in the technology of numerous novel porous sheet materials which are intended for a wide variety of conventional textile, leather, and other applications. Much progress can be attributed to the commercial availability of improved or different raw materials and machinery in various industries. Polymer science and plastics technology played important roles in several new processes for making nonwoven fabrics directly from pellets of thermoplastic polymers.

Some recent developments have been motivated by factors which supplement the usual considerations of cost and physical properties. These include (a) man-made simulations of real leather and fur, (b) acceptance of limited use items which tolerate only several laundering cycles, and (c) the popularity of disposable items for only one cycle of usage without any launderings. Also, a newly emerging fabric formed fabrics industry is exploring the suitability of novel materials for automated fabrication of end items.

The Army is currently considering these novel materials with respect to where they (a) offer adequate (or superior) performance, (b) are more cost effective, or (c) may serve as acceptable emergency substitutes for more desirable materials which may not always be available in adequate quantities. In particular, the Army is concerned at this time about the future capability of the conventional textile industry to respond adequately to major mobilization requirements.[1] It is obvious that the military potential for material which can be produced with fewer processes and faster speeds should be fully assessed.

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1. Kennedy, S. J., "The Changing Capability of the Textile Industry to Support National Defense," USANLABS Technical Report 73-50-CE, April 1973.

As shown in Table I, some nonwoven fabrics can be produced at much faster rates than woven and knitted fabrics which use pre-formed yarns. Hopefully these and newer processes can provide additional options for procurement of materials and fabricated end items.

TABLE I

TYPICAL PRODUCTION RATES AND WIDTHS OF POROUS SHEETS

Process	Rate	Width
Paper	305 m/min	9 m
Nonwoven Fabrics:		
Spunbonded	76 m/min	3 m
Chemically bonded staple fibers	15 m/min	1.4 m
Mechanically bonded staple fibers	3 m/min	6 m
Knitting	1.5 m/min	1.5 m
Weaving	0.1 m/min	1.1 m

The Army is aware of several other logistic problems which exist. Inflation may continue to discourage textile manufacturers from investing in new equipment, and thereby further erode industrial capacity. At least 40% of the mills rely on natural gas for power generation and process heat, and shortages of this fuel, especially in the Southeast, are now imminent. Furthermore, during 1974 and 1975 the uncertainties of supplies and prices were dramatically demonstrated for both natural and synthetic textile fibers.

The possibilities for substituting impermeable films, sheets and composites for the conventional textile materials are being considered in the normal conduct of Natick Development Center programs. However, the present study is directed to materials for possible applications where significant levels of air and moisture vapor permeability are essential or desirable.

The objectives and approaches of this project involved three primary phases of activity. Initially, the full spectrum of novel porous sheet materials was to be identified on the basis of possible

relevance to the needs of the Army. Then, the identified materials were to be evaluated for practicality on the basis of properties suitable for end items, relative cost, and prospective commercial availability or production feasibility. Finally, appropriate action to be implemented would be recommended where the probability for technical success might be high. This could include development of materials in-house by Natick Development Center and/or by industry under contract. This might involve material which has a questionable future in the civilian sector, but is more adaptable to military use and needs. Further evaluation of materials for end item use would normally be required and fabrication of end items for test would be appropriate in some cases. As the project progresses, newer concepts will tend to evolve with changes in the state of the art.

This interim overview of the problem area reports on certain major technological and commercial trends which are now evident. It is now possible for a prudent investigator to state some reasonable conclusions and recommendations for implementation.

PROCEDURE

Initially, all readily available in-house sources of information were screened to avoid duplications of previous efforts. This included a large collection of patents and also data and samples furnished by industry in recent years. The requirements of specifications and previously evaluated or proposed uses of materials were also considered.

Next, a literature survey was conducted to establish a realistic matrix for studying the porous sheet materials which are available or conceivable. The key references actually used were Applied Science and Technology, World Textile Abstracts, and surveys by the Rando Machine Corporation. However, Natick Development Center sources were recently supplemented by receipt of a Bibliographic Series from The Institute of Paper Chemistry. Exhaustive searching of these references by conventional reading techniques was not attempted because new computer techniques are more cost and time effective. A small amount of data was also retrieved from the unclassified technical reports and work units of the Defense Documentation Center's computer.

In a later stage, a collection of references and abstracts covering 1950 through most of 1974 was programmed for the computer of the North Carolina Science and Technology Research Center. The sources were magnetic tapes furnished by the Massachusetts Institute of Technology, the Institute for Textile Technology, and World Textile Abstracts. The 5092 items retrieved (in 10 bound volumes) have been generally screened and are available for further specific reference purposes as the project proceeds.

Numerous industry contacts were made to obtain literature, samples, and oral presentations to further reveal both commercial and research and development trends. Also, the Natick Development Center Foreign Intelligence Advisor initiated requests through established channels to obtain reports and samples from overseas.

RESULTS AND DISCUSSION

A. General Characteristics of Materials and Processes

This study has involved a variety of applicable industries, sciences, technologies and product categories, involving the fields of polymers, textiles, plastics, paper and product fabrication. However, analysis of the various flexible porous sheet materials showed that only three elementary structural features are pertinent, and that these to a considerable extent govern physical performance.

1. The fibrous structure can provide excellent strength due to the high integrity of crystalline polymers oriented along a fiber axis. Since there is considerable latitude in the type and extent of mechanical or chemical bonding of fibers, physical properties of the resulting fabrics can be controlled to give wide variations.

2. A "continuous" film, particularly if microporous or perforated, normally has good strength in only one direction because of limitations in the orientation of polymer structure.

3. Foams tend to be weak because the lower strength of non-crystalline rubbery polymers is further reduced by the pore structure.

Composites of the above three elements can potentially offer the widest range of physical properties. However, it seems that simple systems, rather than complex combinations, are most likely to result in low product cost and high production rates.

B. Nonwoven Sheets

Of the three basic structural categories, the fibrous web systems continue to appear as the most favorable and versatile, as also seems verified by the judgement of industry as evidenced by capital expenditures. These fiber systems and other systems for porous sheets offer the following construction options. Also, Appendix A shows typical relative properties and potential for these nonwoven sheets.

1. Dry-laid Webs of Staple Fibers

During 1974, about 50% of nonwoven fabrics were produced by older processes involving dry-laid webs of staple fibers which are

chemically and/or mechanically bonded. Such webs are utilized in a wide variety of disposable, semi-durable, and durable products. The technology for the processes is being continuously upgraded, but past changes in materials and equipment appear to have resulted in only marginal product improvements.

Nonwoven fabrics made by chemically bonding webs of staple fibers are now substantial commercial materials. Chemical bonding between fibers can be achieved by the application of resin solutions, latices, or thermoplastic powders, or by use of thermoplastic fibers in whole or in part. However, in general, the applications for these materials are limited because of the high penalty in the trade-off between strength and durability vs. fabric-like flexibility.

Nonwoven fabrics made from mechanically bonded staple fibers have web integrity maintained solely by fiber friction and entanglement. This permits greater web flexibility because of some freedom due to fiber slippage. Felting and needlepunching are established older techniques for entangling the fibers. These processes are most applicable to thicker webs, though thinner webs may also be reinforced by light chemical bonding.

Since the technology and products of this now fully commercial class of materials are well known, no detailed discussion of them will be made in this report except in comparison to the more novel types of materials.

2. Wet-laid Webs of Staple Fibers

During 1974, about 15% of nonwoven fabrics were made by wet processes using modified papermaking techniques. These were produced primarily for disposable products such as diapers, wiping cloths and medical supplies. Such processes result in a low cost product, but the capital investment for equipment in competitive high-volume plants is very high. The raw materials commonly used are blends of viscose staple fibers and wood pulp with bonding agents. Sometimes the products are composites of paper and a scrim fabric.

Although the older wet processes have not produced durable fabrics acceptable for military applications, they possess a unique production advantage which should not be overlooked by the Army when considering industrial mobilization plans. Papermaking equipment has been adapted to nonwoven production by modifications to permit processing of longer staple fibers in combination with paper fibers. Resin or latex binders are added to the fiber slurry or otherwise applied by coating or impregnation. The high yardage rate of a paper mill is reduced, but the output

for a single large plant is still impressive. This may offer a good opportunity for obtaining sufficient quantities of semi-durable materials to replace cotton duck used in or needed for tarpaulins and tentage. Furthermore, flammability problems could be minimized because fire retardant treatments for cellulosic fibers are available.

Also, the basic web process for nonwovens has an additional advantage for the nearly complete formation of shaped clothing items or components. Historically, a major obstacle to lowering the initial purchase price of disposable nonwoven garments made from flat preformed sheets has been the high cost of "cut, make and trim" operations which are labor intensive. Automated mass production of garments by shaped sheet formation techniques could radically reduce such costs.

It is reasonable to anticipate that the major part of semi-durable nonwoven utility garments such as coveralls, jackets, trousers and hats, can technically be made in a porous, garment-shaped form. In a typical wet process, fibers suspended in an aqueous slurry (or foam) are formed into a wet web as water is physically removed and the final sheet is dried and given additional fiber-to-fiber bonding as required. Fiber specie, length, bonding, structure, and arrangement are primary variables for the control of physical properties. Stiff products result when ground wood fibers of short length are used to make molded pulp items such as egg cartons. However, it is known that a drapable nonwoven can result when a thin sheet is made from longer length fibers with dimensions similar to some textile fibers.

Perhaps such a process could be used to form garments from a slurry of fibers in a latex. Similar technology exists for a rubber glove production process which involves the formation of films inside of plaster molds containing a latex. The film thickness gradually increases as the water diffuses into the porous structure.

3. Spunbonded Nonwovens

The spunbonded type of nonwoven fabric was first introduced during the 1960's and its great technical promise for the future is verified by intensive research and development efforts as shown by a recent surge in patent activity. Reported production figures show that spunbonded fabrics are already commercially outstanding insofar as they represented 25% of the total nonwovens market during 1974. This share of the market will probably go higher due to an extraordinarily rapid rate of plant expansion. During this current recession in which the conventional textile industry has been a major casualty, and the annual increase in total nonwoven production has been only 12%, the spunbonded segment of the industry has advanced at 20% per year.

The spunbonded processes form nonwoven fabrics directly from thermoplastic polymer compounds in an integrated operation. Continuous filaments of polyester, polyolefin, or polyamide are melt spun; drawn in a high velocity stream of heated air to orient the crystalline structure; and then deposited on a surface as a random or partially controlled ((oriented) web is formed. Bonding may take place by an application of heat and/or pressure to the thermoplastic fibers in the web, or by use of a separate chemical binder technique such as HCl treatment of nylon 66 fibers or polyester bonding agent with polyester fibers. The continuous filaments tend to require less bonding than do staple fibers in order to maintain integrity of a web, but there is still a limiting trade-off between strength and flexibility.

Small companies and manufacturing plants which are typical in the plastics industry appear to be commercially feasible for such products, though the initial cost of a single economical production line may be quite high. In the United States, duPont and Monsanto have long been identified as spunbonded fabric manufacturers, but Kimberly Clark and Crown Zellerback are among the additional forms active in the field. The products of these companies are identified in Appendix B.

Spunbonded fabrics are produced with a wide range of physical properties which vary in accordance with polymer type, fiber denier, extent of bonding, etc. Tables II, A, B and C are from duPont data,[2] which compare the standard laboratory properties of typical commercial spunbonded products with those of some conventional materials which the spunbonded products might replace. The data are expressed in test results customary for each category of application. In general, these synthetic spunbonded fabrics can have tensile, tear and burst strengths superior to those of woven cellulosic fabrics of similar (or greater) weights.

Spunbonded fabrics are inexpensive in comparison with knitted and woven structures, being in the range of \$2 - \$5/kilogram compared to a typical 136 g/m^2 woven polyester industrial fabric at \$7/kilogram. Also, their thermoplastic and surface characteristics are compatible with the new sonic sealing and molded-fabric techniques, which may permit additional cost savings during end item fabrication.

2. Hentschel, R. A. A., "Spunbonded Sheet Products," Chemtech, Page 32 January 1974.

TABLE II A

COMPARISON OF PROPERTIES FOR SPUNBONDED POLYESTER FABRICS

Property	Fabric			
	Spunbonded Polyester		Woven	
	Straight Fiber	Crimped Fiber	Polyester (38 x 33)**	Cotton* (38 x 39)**
Basis, wt, g/m^2	119	119	122	122
Thickness, mm	0.48	0.53	0.30	-
Grab tensile, N***	503	338	605	245
Tongue tear, N	32	32	17	-
Air permeability, $cm^3/sec . cm^2$	97	126	37	-

* Balloon cloth covered by Specification MIL-C-332F, Type IV, Class 1
** Yarns/cm
*** 2.54 cm test width

TABLE II B

COMPARISON OF PROPERTIES FOR SPUNBONDED POLYETHYLENE FABRICS

Property	Fabric	
	Area-bonded Spun-bonded Polyethylene	Cotton Sheeting (24 x 24)*
Basis wt, g/m^2	75	92
Thickness, mm	0.20	0.26
Strip tensile, N**	200	146
Strip elongation, %	29	12
Tear, Elmendorf, N	4	13
Mullen burst, kPa	1034	575

* Yarns/cm
** 2.54 cm test width

TABLE II C

COMPARISON OF PROPERTIES FOR SPUNBONDED POLYPROPYLENE FABRICS

Property	Fabric						
				Cotton Fabrics			
	Spunbonded Polypropylene			Muslin	Cambric	Osnaburg	Burlap
Nominal weight, g/m^2	68	102	119	88	139	142	254
Thickness, mm	0.25	0.30	0.33	0.23	0.18	0.46	0.64
Grab tensile, N*	347	445	516	62**	116***	267	236
Tack tear, N	218	249	280	18	76	200	45
Mullen burst, kPa	903	965	1034	103	207	723	-
Air permeability, $cm^3/sec \cdot cm^2$	103	66	52	102	102	-	-

* 2.54 cm test width

** Approximately 134 is a more typical value for this weight.

*** Approximately 200 is a more typical value for this weight.

In the past, consumer acceptance of spunbonded fabrics has been hindered by the characteristic of nonuniform fiber distribution within the webs. However, this appears to involve a problem in machine design and operation which can be reduced with improved technology as has been experienced with other fibrous webs such as paper and staple-fiber nonwovens. There has been some progress in developing more uniform nylon webs and similar improvements can be expected for spunbonded webs made from other polymers.

Producers have suggested numerous uses for these spunbonded products, and in many cases they appear to parallel existing applications of conventional nonwoven fabrics made from staple fibers. Most of these products are consumed in the home furnishings market, e.g., carpet backing made from polypropylene.

Spunbonded fabrics are now used to a limited extent as components of military end items. The applicable materials and specifications are summarized in Appendix C. The spunbonded nylon is used as a sleeping bag diaphragm because it is readily available (currently) at a low cost, and has adequate strength, flexibility, and coverage to prevent migration of feathers and down while adding little to the weight of the bag. The polyester type is used for clothing and interlining because of adequate bulk and stiffness at relatively light weight. For both the diaphragms and interlinings, the material is durable and is not adversely affected by repeated launderings. The polyolefin types are not used in products within the investigator's purview since they have not as yet met performance requirements for such products.

A variety of potential military uses have been investigated for spunbonded nonwovens. The following summarizes such Natick Development Center activities covering the past three years:

a. Overwhite parkas made from pointbonded polyethylene webs were tested at Fort Greely, Alaska during February 1972.[3] The fabrics used, duPont Tyvek Style Nos. 1443E (44 g/m^2) and 1621E (39 g/m^2), were selected with emphasis placed on opacity. The parkas sustained rips and abrasions after 12 days of testing and questions were raised regarding resistance to heat and flame. Accordingly, the further application of this type material for such parkas is contingent on the availability of more durable products having similar weight, opacity and flexibility characteristics.

3. Letter Report of Engineering Design Test of Parka, Overwhite, Synthetic Materials, Nonwoven, TECOM Project No. 8-EI-484-000-035, dated March 1972.

b. During April 1974, Natick Development Center furnished technical support to the Training Aids Management Agency (TAMA) and explored the possible use of pointbonded polyethylene (Tyvek) webs for disposable "agressor" uniforms.

c. During 1972 and 1973, Natick Development Center considered the use of small cargo parachutes (10 to 12 m diameter) made from nylon (Cerex) webs. This was originally based on a commercial development of Raven Industries, Inc. on cruciform type parachutes. Work was discontinued because the "expendable parachute" material tended to deteriorate with repeated drops, as occurs in training. Furthermore, it was desirable to have lower air permeability without resorting to heavy calendering, and more uniform webs for control of air permeability and structural reasons.

d. Natick Development Center has been continuously reviewing nonwoven fabrics for use as clothing interlining. Various spunbonded types, e.g., polyester (Reemay) and nylon (Cerex) webs, are being considered as alternates to woven interlinings for garments.

e. A Natick Development Center patent titled "Reinforced Carbon Fabrics"[4] describes a potential military application for polyamide and polyester lightweight spunbonded webs (less than 34 g/m^2) as adhesive fabrics which can be activated by heat and pressure. These products are available from U. S. M. Chemical Company under the trade name Bostik. Such adhesive fabrics may have potential for laminating readily available and lightweight woven, knit or nonwoven fabrics, and possibly paper, to achieve composites which can be used in tentage, equipage, etc. as emergency substitutes for duck and webbing, when the latter materials are in short supply.

f. At the present time no major structural or shell application for spunbonded fabric in the military system has been identified. However, the proposed use of polyester (Reemay) or nylon (Cerex) webs as a replacement for osnaburg target cloth was referred to Armament Command (ARMCOM) for practical evaluation during early 1974.

Other possible exploitations of spunbonded materials have been considered. Polyethylene (Tyvek) webs are available as a paper-like material which is area-bonded and can be direct printed to produce tags and labels. This category of spunbonded nonwovens may have potential for inclusion as an option in Specification DDD-L-20 covering Label; for Clothing, Equipage and Tentage (General Use).

4. McQuade, A. J. and Arons, G. N., U. S. Patent 3,850,785, 26 November 1974.

However, it is to be recognized that the temperature sensitivity of polyethylene would prevent high temperature launderings and ironing, thus necessitating use of another polymer with a higher melting temperature.

Spunbonded webs with impregnations or microporous coatings might be suitable replacement materials in some duck or webbing applications. As a more remote possibility, webs of edible protein fibers from soy protein isolate (used for meat analogs and extenders) might be valuable for disposable items such as a cargo parachute, which can feed a starving population. It has even been suggested that such parachutes could disappear from a drop zone since they are biodegradable or possibly animal food.

There are conceivable variations of the spunbonded process in which the initial continuous filament extrusion stage could be omitted. Preformed continuous filaments or yarns could be used for the preparation of similar web types. A good example is a recent patent titled "Nonwoven Articles Made by Coating Filament with Binder and Drying the Binder Until Non-Migratory Before Providing Filament-to-Filament Contact".[5] Claims are made for the formation of a garment by projecting coated fibers or yarns on a hollow preformed mold. The deposited nonwoven structure is held in place with suction and residual solvent in the binder is dried to complete bonding. Supplemental claims are found in two more patents which are titled "Nonwoven Articles Made From Continuous Filaments Coated with Discrete Droplets"[6] and "Nonwoven Articles Made From Continuous Filaments Coated in High Density Fog with High Turbulence"[7]. This method is particularly suitable for making garments of elastomeric fibers, not easily handled in ordinary production machinery.

The spraying of staple fibers with wet or dry binders would be more economical than similar techniques with yarns, and perhaps a more uniform web is possible. Wet binders could be dried or cured by heat, whereas dry binders could be activated by heat and pressure from an outer mold. The reinforced plastics industry already has some technology for spraying fibers with wet binders, for example, in the construction of fiberglass composite boat hulls.

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5. Paquette, E. G. and Guenther, K. R., US Patent 3,755,036, dated 28 August 1973, assigned to Bjorksten Research Laboratories.

6. Paquette, E. G. and Guenther, K. R., US Patent 3,775,209, dated 27 November 1973, assigned to Bjorksten Research Laboratories.

7. Paquette, E. G. and Guenther, K. R., US Patent 3,775,210, dated 27 November 1975, assigned to Bjorksten Research Laboratories.

The properties of spunbonded fabrics could be modified by their incorporation into composites. For example, other materials could be combined to provide higher levels of opacity and thermal insulation. Cerex spunbonded polyamide fabric of 11 g/m^2 weight treated with wood fibers and binders to give composites weighing 44, 75 and 109 g/m^2 has been considered. The projected cost for the 75 g/m^2 material is in the low range of \$0.13 to \$0.16/m^2. These initial experimental materials were considered to be too weak, and there was some concern regarding potential flammability. However, progress with reinforced webs and fire resistant treatments appears encouraging.

4. Spunlaced Nonwovens

The new spunlaced type of nonwoven fabric appears to involve the highest rate of expanding production in the nonwovens industry, (while the preceding spunbonded category has the next highest expansion rate). The duPont Company is promoting its spunlaced grey (unfinished) goods under the trade name "Sontanara" outside the United States, and at present the sole US converter is Burlington Industries, which markets such products under the trade name "Nexus".

The fabric is held together solely by fiber entanglement and friction, in predetermined repeating patterns, Current production includes only polyester fibers (though other polymers presumably could be used). Newton and Ford[8] elaborated on an applicable duPont patent (U.S.P. 3,620,903, dated 29 January 1970) which claims (a) spunlaced fabrics can be made from a random web of polyester staple fibers; e.g., 1.5 denier and 3.8 cm length, (b) the webs are exposed to multiple passes of high pressure water jets which are in the range of 14 to 95 atmospheres pressure, (c) this gives entanglement of the fibers with sufficient cohesion to permit further use without a binder, and (d) linear processing rates of 18 or 27 m/min are achieved. Other companies have been assigned patents[9] which involve similar processes using fibers or yarns united under fluid jets.

Acceptance of spunlaced fabrics has been based on their potential for durability combined with softness and drapeability approaching that of conventional woven and knitted structures. So far, they have made an impact in the home furnishings field with such items as mattress pads, curtains, bedspreads, and pillow cases. However, such products will not be suitable for apparel applications until improvements in abrasion resistance and resilience are achieved.

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8. Newton, A. and Ford, J. E., "The Production and Properties of Nonwoven Fabrics," Textile Progress, Vol 5, No 3, Page 25, 1973.

9. Winger, J. H. and Burn, W. A., "Fluid-entangled Nonwoven Fabric," US Patent 3,623,935, 30 November 1971, assigned to Celanese Corporation.

Spunlaced fabrics sold under the Nexus trade name are currently available in four basic styles with aperture patterns as the major variations, and with weights varying from 34 to 102 g/m^2. These lightweight fabrics would be expected to contribute to warmth due to their relatively low density, but this has not been verified by realistic thermal insulation tests. Breaking strength and stiffness are normally greater in the machine direction, whereas elongation to break and tear strength are greater in the cross direction. The projected cost for such material in the vicinity of $\$0.007/m^2 \cdot g$ will make it competitive with woven fabrics.

Table III compares the physical properties of some Nexus spunlaced fabrics[10] with some Reemay spunbonded polyester fabrics. These data are for grey goods, and final properties may be influenced by heat setting and various finishing processes. The spunlaced fabrics have tensile strength/weight ratio which compares favorably with that of the spun-bonded polyester fabrics, and claims are also made for good comparative burst strength. However, the Nexus fabrics tend to be thicker than Reemay and other nonwoven fabrics of the same approximate weight.

These Nexus fabrics made from thermoplastic fibers are considered to be suitable for make-up by ultrasonic seaming and also have potential for molded fabric applications. It is conceivable that they could be used in automated garment cutting and fabrication operations.

Consideration was given to the possibility of using Nexus for a white outer parka for arctic camouflage, and it was found that improvements in opacity are required. A sample Nexus coverall is now being evaluated for possible use in maintenance operations by combat vehicle crewmen. Nexus samples are also being evaluated as thermal insulation, pillow ticking, sleeping bag liners, and camouflage covering of helmets.

5. Stitchbonded Fabrics

The general term "stitchbonded fabric" otherwise referred to as "stitch-through fabric" covers an important contemporary variety of nonwoven webs which must be seriously considered by the Army. Fabrics produced by the several stitchbonding processes often have a conventional appearance and feel, but they have unique structures and are produced at much higher production speeds than woven and knitted materials. The basic process types and some common machine trade names are summarized in Table IV.

10. Guenther, H. W., et al, "Nexus" Spunlaced Formed Fabrics," Modern Textiles, Vol 54, No 12, Page 40, December 1973.

TABLE III

PHYSICAL PROPERTIES OF NEXUS AND REEMAY FABRICS

Physical Property	Nexus Fabric Style				Reemay Spunbonded Style		
	Diagonal Apertured	Non-Apertured	Square Apertured	Lace	2016	2415	2430
Weight (g/m^2)	41	64	81	58	47	51	92
Tensile Strength, Grab (N):*							
Machine Direction	116	218	227	107	—	85	183
Cross Machine Direction	71	138	169	85	—	71	151
Elongation, Ultimate (%):							
Machine Direction	48	42	47	47	—	—	—
Cross Machine Direction	99	86	81	84	—	—	—
Thickness (μm)	457	508	660	—	305	330	457
Air Permeability ($cm^3/sec.cm^2$)	329	117	—	—	—	—	—

* 2.54 cm test width.

It is interesting to note that the Warsaw Pact Nations, especially the USSR, are reported to produce increasingly large quantities of such fabrics. Although the stitchbonding machinery is manufactured primarily in East Germany (Malimo types) and Czechoslavakia (Arachne and Araloop), some has been imported into this country with successful results. Appendix D summarizes performance data claimed by the manufacturer of Malimo machines.

TABLE IV

STITCHBONDING PROCESSES AND MACHINES

Process	Machine *
Stitching warp and filling yarns which are not interlaced. Produces fabric similar to woven fabric.	Malimo - type Malimo
Stitching of a pile onto a substrate to form terry cloth or other pile fabric.	Malimo - type Malipol or Araloop
Stitching a batting with yarn to form fabric.	Arachne or Malimo - type Maliwatt
Stitching a batting without yarn to form fabric (stitching-like yarn produced in situ from fibers within the batting itself).	Malimo - type Voltex (uses prefabricated backing) or Malimo - type Malivlies

* Same terminology used for fabrics produced on these machines.

Since US stitchbonded fabric manufacturers are still undergoing major transitions involving evaluation of machines and fabric development, it would now be premature to draw any final conclusions regarding the merits of each process. Meanwhile, it is advantageous to examine the state of the art and anticipate product improvements.

Malimo-type Malimo fabric can be produced at a rate of 250 cm/min, which is considerably faster than the 5 to 25 cm/min common with looms. It is entirely a yarn structure with filling yarns laid across a warp sheet and then both warp and filling stitched together by a third set of yarns. The warp and filling yarns remain straight since there is no

crimp introduced by interlacing. This process tends to give stiff fabrics and low coverage, but even more important is the lack of stretch which results in strain being concentrated at stitching yarns. In the past, production costs have not been significantly lower than that for woven fabrics. However, such materials have been used for household, outerwear, and industrial applications.

There is a recent variation of the Malimo-type Malimo fabric which consists of stitched filling yarns, i.e., warp yarns are omitted. Since the structure is similar to that for the weft-insertion warp-knit process, comparable properties are anticipated.

Stitchbonded webs of staple fibers made on Malimo-type Maliwatt or Arachne machines tend to be lower in cost since most of the weight and cost apply to staple fibers rather than more expensive yarns. This construction tends to permit fiber migration which results in pilling and low abrasion resistance, unless long fibers (13 to 18 cm in length) with a coarser denier are used. If the long fibers are used, then only heavier weight fabrics (over 136 g/m^2) with a crisper handle will result. Since stitching runs along the machine direction, the long coarse fibers must be laid across the web (at a right angle to the machine direction) in order to assure maximum cross-strength. Since these fabrics can be fluffy and voluminous thereby offering excellent thermal insulation, a major commercial end item application has been blankets. These processes have also been used for outerwear by using polyester/wool stitched with polyester, but increased durability attributed to close stitching results in a trade-off in greater stiffness.

In terms of industrial mobilization it appears that stitchbonding webs of staple fibers offers a means of overcoming materials shortages. If parts and service are available, Malimo-type Maliwatt and Arachne machines can probably consume a large quantity of fibers for conversion into blankets.

The Malipol and Araloop types of stitched loop-pile fabrics have loops formed by stitching through a base fabric (or a foam sheet). Products normally consisting of single sided terry cloths such as absorbent towelling can be made from cotton scrim with a cotton pile. The pile yarns can be brushed or raised on one or both sides to produce bulky fabrics suitable for linings, coatings and blankets. Low costs for these composite fabrics are difficult to achieve because base fabric and stitching yarn components are relatively expensive.

A variety of stitchbonded fabric samples of all types were obtained from several firms. Preliminary evaluations were conducted only on several fabrics which were available in an adequate sample size. A sample of wool fabric[11] made from stitched warp and filling yarns appeared to show promising characteristics for a suiting fabric in terms of excellent tear strength, low shrinkage after laundering, satisfactory ultimate elongation and high porosity. In contrast, sample fabrics consisting of only stitched filling yarns[12] compared unfavorably with conventional woven shirting materials, because they showed a lack of balance in break and tear strengths. Further work including wear tests is warranted, but consideration will favor the more balanced constructions which include warp yarns.

6. Melt Blown Nonwovens

The melt blown process represents some of the important new nonwoven fabric technology which uses thermoplastic pellets as a raw material. It is now being licensed by the Exxon Chemical Company, with the Beloit Corporation acting as the licensing agent and machinery manufacturer. So far, materials production appears to be limited to a semi-works scale, and the products have not yet been optimized. The projected economies of this process are attractive on the basis of low capital investment and low conversion cost for the resin, including labor, depreciation and energy.

This process is similar to a spunbonded process, but it uses molten polymer and high-velocity hot air in a different manner to form soft and drapable webs of microfibers. These fibers are about 2 microns in diameter (1/20 denier) and several inches in length. Bonding is primarily mechanical, with web integrity maintained by fiber entanglement and friction, but chemical or melt bonding is an option. Fiber and web strength is moderate, since low fiber orientation results in a tenacity of about 1-2 g/den. A wide variety of thermoplastic polymers could be used, but most emphasis has been placed on polypropylene and polyester.

One apparent potential military use for these webs of fine fibers is thermal insulation such as for cold weather clothing, sleeping bags, and tent liners. Natick Development Center will soon evaluate the thermal properties of meltblown polyester and polypropylene webs.

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11. Borges, P. F., "Evaluation of Malimo Suiting Fabric," TR&ED Material Examination Report No. 8578, dated 23 December 1974.

12. Memorandum for Record, dated 16 December 1974, by Paul F. Borges, subject: Malimo Fabrics - First Impressions.

7. Sprayspun Nonwovens

The sprayspun processes are another method of forming nonwoven fabrics directly from thermoplastic pellets. Products still in the developmental stage at the Celanese Corporation utilize off-the-shelf technology now in use for the manufacture of Fram air filters. Samples furnished by the Celanese Research Company show an obviously wide variation in thickness, weight and density for webs made from polypropylene and polyester, but no laboratory data on physical properties are yet available.

The sprayspun processes are similar to the spunbonded processes in that continuous filaments are extruded, given slight orientation from a high velocity fluid jet, and then chemically bonded in controlled or random webs. An essential difference appears just beyond the extrusion stage where the high velocity fluid jet for the sprayspun process is superheated steam, whereas hot air is used for the spunbonded web. It is claimed that superheated steam causes less chemical degradation of the thermoplastic polymer.

A recent patent titled "Method of Spray - Spinning Continuous Tubular Structures"[13] is now dormant because of the cost/performance ratio, but this situation could change as the state of the art improves. An object of this invention is to do away with the necessity of sewing or bonding a nonwoven sheet to produce tubular structures. The filamentary material in the web such as polypropylene, has a varying amount of orientation. It is randomly bonded to itself at crossover points between filament sections so as to form varying lengths. The continuous sprayspun fibrous tube that is formed is subjected to a drawing operation to further improve tensile strength, stretch, and drapeability.

The inventor claims that the sprayspun tubes may be useful in garment structures such as for sleeves or pant legs. However, at the present state of the spunbonded fabric art this represents a limited market for disposable clothing used for clean rooms, in hospital operating rooms and the like.

The availability of such thermoplastic nonwoven tubes suggests that consideration should be given to a major military application such as sand bags. At present, the most economical sand bags in the military supply system are fabricated from woven polypropylene tape

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13. Rich, E. J., US Patent 3,796,619, 12 March 1974, assigned to Celanese Corporation.

which is also referred to as slit film.[14] However, during manufacture of the sprayspun nonwoven tube, supplemental stages could be added to give an integrated operation for fabrication of sand bags from the same polypropylene polymer (or other thermoplastic polymers). This would include automated cutting of the tube and sealing of one open end; e.g., with an ultrasonic device.

Further commercial developments for the sprayspun processes will continue to be monitored by Natick Development Center. However, it appears that the other processes previously discussed are being developed and commercialized in a more dynamic manner.

8. Fibrillated Films and Foams

New advanced technology for the production of nonwoven fabrics made directly from fibrillated (split) film or foam appears to show promise for the future. These processes can have an integrated operation which starts with thermoplastic polymer granules, follows with extrusion into ordinary continuous film or a thin foam sheet, continues with a fibrillation process to form a fiber network and ends with a finished nonwoven web of bonded fibers. Such processes are still under development, but the intensive efforts now underway here and abroad suggest that the probability for success is high.

The most attractive cost reduction feature is a potentially lower capital investment for simplified production lines. Small plants which are typical in the plastics industry, are commercially feasible for such products.

Ole-Bendt Rasmussen, the Danish Inventor, prominent in establishing the modern fibrillated film industry during the 1960's, recently invented a related film-splitting process which may represent a quantum jump in the nonwoven fabrics field. This is documented in his recent patent titled "Filamentary or Sheet-like Material of Polymeric Substances and Method and Apparatus for Producing Said Material."[15] The resulting webs do not consist of conventional fibers, since entirely new categories of polymeric elements in unusual shapes, for example, a variety of spine and tentacle arrangements, are interconnected in the web. These materials may be suitable for some duck and webbing applications and will be evaluated by Natick Development Center, if available from a US licensee when negotiations are completed.

14. Specification MIL-B-52472B(ME), dated 18 August 1969, and Amendment 1, dated 31 October 1969, covering Bags, Sand: Polypropylene.

15. US Patent 3,690,982, 12 September 1972.

The foam fibrillation process of the FMC Company is now at a semi-works stage of 1,000,000 kilograms per year capacity. Conversion of thermoplastic pellets into a primary lightweight fibrous web costs an estimated $0.11 per kilogram which is competitive with the spunbonded and meltblown processes. Furthermore, high linear production speeds of 60 to 66 m/min have been achieved, and relatively low capital investment is required.

In the foam fibrillation process, pellets containing ordinary thermoplastic polymers are foamed and extruded in commercial plastics machinery. A lightweight tubular foam structure emerging from a circular die is fibrillated by expansion over a mandril and is then slit to achieve a flat fabric. The resulting webs weigh only 7 to 17 g/m^2 and must be given further processing such as orientation to improve fiber strength and plying to achieve heavier fabrics for most applications.

At present, the primary application for such foam products is adhesive scrims, but there is a growing market for clothing interliners. Natick Development Center evaluation of materials would be premature until the process is optimized for web strength and weight.

9. Nets

There is another direct route for making nonwoven fabrics directly from thermoplastic pellets converted into a plastic film. A film can be converted into a nonwoven fabric of the net type by embossing and then stretching to give an open structure with larger size elements. This is the process used by Hercules, Inc. to manufacture polypropylene nets sold with the Delnet trademark. Delnet has been marketed for fabric bonding purposes such as for fusible interliners. Conventional textile applications for a product of this type are dubious until physical properties are upgraded by improved net designs and better control of orientation for fiber-like elements.

Delnet (and other adhesive fabrics) were the basis for a potential adhesive application described in a recent Natick Development Center patent titled "Reinforced Carbon Fabrics".[4] The mobilization planning potential for such adhesive fabrics should not be overlooked by the Army. They could be useful for laminating more available lightweight woven, knit or nonwoven fabrics and possibly paper to achieve composites which can be used as emergency substitutes for duck and webbing required for tentage, equipage, etc.

There is an entirely different technique of producing nets directly from thermoplastic pellets, but this requires the use of special circular dies which extrude crossed ribs. Nets of this type, which omit a film extrusion step have been suggested for fruit packaging applications, but the implied military value of such products is questionable, since absence of a polymer orientation step would result in low strength.

10. Microporous Sheets

There is an uncertain future for various microporous flexible sheet materials which might be used for footwear, water repellent clothing, tentage, and tarpaulins. Most of these materials generally lack the desirable feature of relatively high water vapor permeability. So far, neither unsupported microporous films nor fabrics laminated or coated with a microporous polymer have been demonstrated as commercially feasible for such applications. In contrast, the poromerics (synthetic leather) with different structural features have achieved significant success worldwide as a leather substitute for shoe uppers. Due to uniqueness of the various sheet categories, each will be discussed separately in the following sections.

a. Microporous Films:

Microporous polypropylene film has been marketed by the Celanese Plastics Company under the trade name "Celgard." The film is made by extrusion with a high stress and low melt temperature, annealing without tension, stretching to develop pores, heat treating with tension, and possibly coating with a hydrophilic material. This product is waterproof at atmospheric pressure, but is permeable to air and water vapor. Typical pore sizes are less than 2000A (0.2 μ) in length and 200A (0.02 μ) in width. This product and similar ones from other manufacturers were developed primarily for non-textile applications such as the reverse osmosis technique of water desalination, battery separators, and microfiltration. No potential applications for Natick Development Center end items are apparent for such unsupported films.

b. Microporous Composite Sheets:

It is claimed that Celgard film can be laminated to fabrics, including nonwovens, with up to 90% retention of porosity. Adhesive bonding without further treatment is possible because of the high surface area of the film; i.e., 50 m^2/gm. Lamination would be used for applicationswhere high impact and tear resistance are required. Celanese has suggested a number of potential end uses which are relevant to military applications. These include sleeping bag fabric, tarpaulins, tent fabrics, thermal blankets, protective clothing and raincoats.

Other coated or laminated fabrics with microporous polymers are available as waterproof sheets which are water vapor permeable.* A variety of polymers and methods of pore formation are involved. W. L. Gore and Associates, Inc. produces such microporous products under the Gore-Tex trade name. These are from expanded polytetrafluoroethylene (PTFE) resin available as porous sheeting which is laminated to fabric or polyurethane foam. At present, Natick Development Center is evaluating a laminate of nylon fabric/PTFE film/nylon fabric, weighing 96.6 g/m^2, for use in Parka and Trousers, Wet Weather. Recent physiological heat stress data indicate that the level of stress for Gore-Tex garments is comparable to that for 193 g/m^2 Quarpel treated polyester/cotton poplin. This material will probably tend to be expensive due to the high cost of PTFE resin.

In earlier work on similar laminates, Natick Development Center had a contract with the American Cyanamid Company for development of laminated (fabric supported) materials (Contract No. DAAG 17-72-C-0080).[16] The porosity was achieved by blending two resin phases and extracting one phase with a solvent.

c. Microporous Fibrous Sheet:

Two recent patents[17] describe extensively fibrillated thermoplastic webs or mats which use polymer technology from the basic laminate development by American Cyanamid Company described above. These unsupported microporous sheets have the form of nearly continuous and integral three-dimensional works or structures containing interconnected ribbons. The ribbon-like structures have their principal surfaces arranged parallel to the plane of the sheet. During production the network is aligned principally in the machine direction and considerable orientation of the semi-crystalline polymer; e.g., polyethylene or another polyolefin, takes place. Accordingly, it is not surprising that tensile properties are quite directional. Tensile strengths as high as 8960 kPa were reported but at this early stage of development physical properties may not be optimized. Average void thickness (smallest dimension of void) is approximately one micron (10,000 A).

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* These categories exclude the open celled foams which are macroporous and are considered separately in this report.

16. DeLapp, D., "Development of Laminated Fabric Materials", USANLABS Technical Report 73-21-CE, August 1972.

17. Gallacher, L. G., US Patent 3,783,093, 1 January 1974, and US Patent 3,796,778, 12 March 1974, both assigned to American Cyanamid Co.

These two American Cyanamid Company patents describe a method in which a solid particulate thermoplastic resin which is insoluble in a selected leaching solvent is mixed and fibrillated under heat and pressure with another thermoplastic resin which is soluble in the same solvent. Following fibrillation, the resin mixture is subsequently contacted with the solvent to remove the soluble resin thereby leaving an extensively fibrillated thermoplastic resin product, which may be used as a synthetic fabric.

A variety of equipments commonly available in the rubber and plastic industries; e.g., twin-screw extruders and two-roll mills, can be used for all processing stages prior to removal of the soluble resin. Existing plants would require the addition of a solvent extraction system. This should include provisions for recovering the extracted resin and solvent for reuse. If an integrated operation is not feasible, then the resin extract solution could be separated at a commercial solvent recovery plant located elsewhere.

The description of this novel sheet material suggests that similar processes might be developed for thicker flexible strips which may be a suitable alternative for some webbings required under industrial mobilization plans. Webbing such as in the soldiers' load carrying equipment is often greatly overengineered in terms of breaking strength. These materials are selected primarily on the basis of other practical considerations which include width and stiffness. In such cases, a decrease in breaking strength can be tolerated providing other requirements are met. However, at this stage of the study it appears that other processes are simpler and potentially more economical for the manufacture of webbing.

d. Poromeric Sheets (Synthetic Leather):

Commercial poromeric materials made from impregnated and coated nonwoven fabrics tend to imitate many features found in actual upper leather of shoes for a variety of reasons. Comparable moisture vapor transport, appearance, stitch tear resistance and tear strength are important to satisfy consumers. The manufacturer is able to adapt sheets which can be split and buffed on conventional leather processing equipment. Departing from the leather imitation, however, it is more advantageous to use large uniform man-made sheets with a fairly stable price rather than rely on irregularly shaped small leather pieces which are subjected to variations of the commodity market.

Certain material improvements are needed to overcome remaining consumer resistance in the shoe application. These poromeric materials have a typical moisture absorption capacity of 7 to 10

percent, whereas leather, which absorbs sweat to a greater extent is in the 30 to 40 percent range. Unfortunately, they lack leather's comfort feature of a gradual foot conformation, which is referred to as "breaking-in". Furthermore, the price of these man-made sheets has not been significantly lower than that of leather.

In the production of commercial poromeric materials, it is common to impregnate nonwoven fabric with open-celled foams of linear, segmented polyurethanes. These foams are microporous (average cell size below 50 microns) and have densities in the 0.3 to 0.8 g/cm^3 range. The foam/nonwoven composite is finished with a separate topcoat layer to resemble real leather. However, one new poromeric product, Porvair, has a foam layer which does not include a nonwoven fabric as the load-bearing substrate. Perhaps a satisfactory leather-like glove can be economically produced from such a foam by direct formation on molds. The rubber glove industry could provide some useful supporting technology.

The probable use of poromeric materials as a substitute for conventional textiles appears to be uncertain. The high density and other leathery characteristics of the poromeric sheet are detrimental for some garment applications. However, it is conceivable that fashion considerations may influence the use of such products in leather-like caps and field jackets.

11. Flocked Fabrics

Several years ago, the flocking industry advanced with new processes for flocking by the electrostatic application of short fibers to substrates coated with adhesive. Some of this activity was influenced by fashion considerations such as the need for breathable imitation suede which is competitive with the real leather product. The industry is now reported to be undergoing a decline, as shown by the 1973 US production figures which was only half of the 1972 peak.

Thermal insulation in garment liners is one of the more obvious potential military application for flocked fabrics. It is questionable whether insulation efficiency of flocked fabrics will approach that of quilted batting materials. The latter have partially superseded knitted and woven pile fabrics, where weight reduction is critical, as in field clothing. Accordingly, US Army Natick Development Center will minimize further consideration of the flocked webs.

12. Bonded and Laminated Thin Foams

Bonded and laminated thin foam sheets reached the peak of their popularity during the late 1960's, and then the industry appeared to decline rapidly. These foams were intended to provide thermal insulation with

minimum weight and to stabilize lightweight knits. The material commonly used was a thin open-celled polyurethane foam and flame bonding to knits was a dominant technique and application. A factor in the decline was probably competition from piled or quilted materials which are satisfactory for clothing insulation, sleeping bags, or other applications involving thermal insulation.

Laminated foam sheets can be incorporated into more complex composites which consist of foam, fabric and other materials. For example, flocked foam blankets[18] are one commercial application which offers the military a choice of alternative materials in case of shortages of woven wool blankets during mobilization. These blankets are produced by the application of a flock to a substrate prepared by flame lamination of foam to a stabilizing scrim. However, the relative merits of this process must be further compared with competitive processes such as stitchbonding staple fibers.

Some recent technology on foam coated fabrics is described in a recent patent, titled "Acrylic-Nitrile Foam-Backed Fabric and Method of Preparation."[19] Claims are made for an acrylic foam-coated fabric which provides air permeability, thermal insulation and resistance to laundering and dry-cleaning. Included are the usual textile patent claims for a product which is flexible and has a good hand. In the process, fabric is coated with an air-froth of cross-linkable acrylic-nitrile latex, and the foam coating is dried to a semi-rigid state. The semi-rigid foam coating is calendered to crush and densify the coating, which is then cured. This concept of a porous crushed foam-coating on fabric is not new, as it has been successfully used during the past several years for drapery backing, and other uses such as mattress ticking are expanding rapidly. Acrylic emulsions have been the basis of this industry, and the above invention for an acrylic-nitrile foam backed fabric appears to be a variation which claims an improvement in wash and solvent resistance and hand.

A new technology of flexible polyurethane foam composites may result from recent developments at W. R. Grace and Company. A hydrophilic polyurethane polymer that forms open cell foams upon the simple addition of water is being marketed under the trade name "Hypol". Due to a high water vapor transmission rate it is possible to dry the foams in ambient air in lieu of oven drying. Flame retardancy of the urethane itself is claimed as superior to that of conventional foams.

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18. Brodbeck, M., "Advances in Flame Foam Bonding," American Dyestuff Reporter, Vol 60, No 3, Page 54, March 1971.

19. Torre, P. L., et al., US Patent 3,713,868, 30 January 1973, assigned to General Latex and Chemical Corporation.

Hypol foam polymer has potential in laminated or foamed-in place applications for nonwoven and woven fabrics. Suggested uses include mattress ticking and covers, apparel interliners, blankets, artificial leather and shoe insoles and linings. A unique technique is suggested for producing a self-adhering foamed laminate in a single operation. This involves pre-coating a substrate with Hypol polymer and then passing it through water or steam to induce foaming.

Recently during 1974, the Federal Trade Commission decreed that manufacturers of cellular or foamed plastics must warn users of the serious fire hazards associated with their products. This action is based on laboratory evidence which challenges the accuracy of the terms "non-burning" and "self-extinguishing" used in marketing. Presumably this may retard further development of the foam industry until the problems of flammability and associated toxic fumes are overcome.

13. Miscellaneous Novel Porous Fibrous Sheets

The literature reveals a large number of novel, porous, fibrous sheets which are difficult to classify in the preceding categories. The following examples show an interesting diversity of structures and processes:

a. Nonwoven Fabric by Replication Technique:

Chemplast Inc. developed a technique for replication of a fabric with TFE (tetrafluoroethylene) resin in a slurry or emulsion form.[20] The resin is sintered onto a cellulosic version of the material to be duplicated, and the cellulose is decomposed by baking, leaving a sheet-form layer of resin. Claims are made for pores down to 2 microns, thicknesses from 50 to 875 μm and tensile strengths from 410 to 3100 kPa, which can be improved with composite structures. This material will tend to be expensive due to the high cost of Teflon and the thermal degradation of a cellulosic fabric. It has been used in esoteric applications such as National Aeronautics and Space Administration's skylab and is being promoted in microporous film versions for filtering applications.

b. Nonwoven Fabric Directly from Monomer:

A nonwoven fabric-like structure has been polymerized directly from unsaturated monomers in a crystalline network of frozen solvent.[21, 22] The work vaguely reported appears to cover the preparation

20. Anon, "Process Converts Teflon Resins into Inert, Porous, Fibrous Material," Product Engineering, Vol 44, No. 9, Page 41, September 1973

21. Krauch, C. H., "Polymerisation auf Kristalliner Matrix," Naturwissenschaften, Vol 11, Page 539, November 1968.

22. Krauch, C. H. and Sanner, A., South African Patent 684,578, 13 December 1968.

of samples which are laboratory curiosities. There is no indication that crystalline polymers with orientation were obtained. But this technique has potential which cannot be overlooked.

As a new approach, it is conceivable that unsaturated monomers such as acrylics, which are polymerized as raw materials for commercially successful textile fibers, might be used in combination with an inexpensive solvent such as water. This mixture of liquids could be cooled to a frozen mass and then exposed to ionizing radiation from a Linac or Cobalt 60 source. Defrosting, evaporation and recovery of solvents from the resulting polymer web should not present any difficulties, since considerable processing could be accomplished in conventional textile dyeing and finishing equipment. Stretching of the web or other techniques could be tried to induce fiber orientation. Furthermore, if such a process is feasible for flat sheets it could also be useful for the direct formation of shaped items such as garments and related components.

c. Shaped Nonwoven Fabric Articles by Electrophoretic Deposition from Slurry of Fibers and Binders:

The American Cyanamid Company recently revealed a process using electrodeposition to fabricate nonwoven structures.[23] The basic concept is not new, since rubber gloves have been commercially made by electrodeposition from a latex. This process is similar except that fibers are deposited together with a suspended polymeric binder system. Perhaps a nonwoven sheet shaped as a shoe upper can be electrodeposited and subsequently converted to a poromeric material by impregnation and coating.

d. Nonwoven Insulating Mat from Film:

There are questionable military applications for a new invention titled "Method of Making a Synthetic Resin-Fiber Mat."[24] The patent is vague in respect to properties of materials, but it leads one to believe that insulating mats for clothing, sleeping bags, etc. can be made directly from extruded thermoplastic polymer granules in a small integrated operation. The drawings for a variation of the invention involving a continuous process suggest that capital investment would be low and production rates could be high.

In the patent a thermoplastic film is longitudinally oriented (stretched), then slit to give a unique pattern, and next expanded into an openwork. The web can thereafter be heat-crimped and then finally cut or torn into individual web elements which are piled and pressed to form a fiber mat or felt.

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23. Bankert, R. D., et al., "A New Electrochemical Process for the Fabrication of Nonwoven Materials," Textile Research Journal, Vol 43, No 5 Page 247, May 1973.
24. Balk, H., et al., US Patent 3,806,390, dated 23 April 1974, assigned to Reifenhauser KG.

e. Piled Sheet from Fluid Resin:

There appears to be some potential in a new patent titled "Method of Preparing Pile Surfaced Products from Epoxy Resins."[25] In one sense it describes a film fibrillation process, but the film is actually a viscous fluid which is cured after fibrillation. The product is a pile surface consisting of fibers or tufts of fibers; these are generally attached to a separate foundation material. For flexible and porous products the foundations could be woven or nonwoven fabrics and open-celled thin foams.

The process requires very simple equipment for the application of a tacky uncured polymeric material to the foundation and then contact with a special surface to which it will temporarily adhere. The special surface is separated from the bulk of the liquid polymer whereby adhered fluid fibers are developed by pulling away in a "stringing" action. The fibers, which are attached to the bulk of the polymer at one end and the special surface at the other end, are cured to maintain the fiber integrity, which would otherwise be disrupted by further liquid flow. Then the special surface is parted from the cured fibers emanating from the bulk of the polymer which remains fixed on the foundation. In one variation of the process, the foundation layer is removed in a final stage.

Although the invention title cites epoxy resin, claims are made for a variety of other curable polymers which include styrene/butadiene rubber, polyurethanes, and phenol-formaldehyde. However, this raises questions regarding suitable viscoelastic properties achievable with cross-linked polymers. Normally such materials have not been used for commercial fibers unless very special properties are required and a trade-off in deficiencies is tolerable. Examples of such products are the weak but thermally stable Kynol (phenolic) fibers and weak but highly extensible Spandex (polyurethane) fibers.

The patent suggests applications such as linings for outer cold-weather garments and simulated fur. However, numerous other applications are obvious since this process could conceivably replace flocking. Possibly a low cost blanket or even sleeping bag liners could be made by applying a pile to a nonwoven fabric or open cell thin polyurethane foam.

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25. Jones, M. E., US Patent 3,814,791, 4 June 1974, assigned to Imperial Chemical Industries, LTD.

f. Nonwoven Web Sprayed from Polymer Solution:

The utmost simplicity in nonwoven fabric manufacture is indicated in a patent titled "Fibrous Product from Thermoplastic Polyamide Polymers."[26] In this invention, thermoplastic polyamides dissolved in an organic solvent are sprayed onto a substrate to produce a fibrous mat. This mat can be removed from a release type substrate and be self-supporting. It is comprised of fibers essentially nonuniform in thickness (or diameter) and length, alternating between areas having solid cross section with areas whose cross section is tubular. The fibers thus have along their length a number of nonuniform totally enclosed gas pockets, which presumably may be of interest in thermal insulation and flotation studies. There is a similarity with spunbonded and sprayspun webs insofar as some of the fibers are interconnected or bonded to each other. Also, since the fibers are hydrophobic, the mat is described as water repellent.

In two major respects this process is quite different from the spunbonded and sprayspun processes. The evaporation of a solvent introduces problems in drying and solvent recovery, but suitable technology is probably available from processes involving the dry spinning of fibers. Furthermore, lower strength can be anticipated since no provisions are made for even the lowest level of fiber orientation when a crystalline polymer is used.

An example of possible textile applications is given for a raincoat prepared from cotton cloth sprayed with a fibrous mat prior to cutting and sewing operations. Such materials are likely more comparable to water repellent treated fabrics than resin or rubber coated fabrics which are impermeable to water vapor. This sprayed mat might offer the ultimate in simplified production of a disposable coverall, jacket or trousers.

C. Woven Tapes

An exception has been made to the exclusion of woven fabrics in this study for the reason that thermoplastic pellets could be used in an integrated continuous operation which starts with extrusion of a plastic film and ends with the weaving of oriented tapes into fabric. Such a process is covered in a patent titled "Continuous Techniques for Making Flat Woven Synthetic Fabrics."[27] This process may have industrial mobilization potential, since similar woven materials already made from plastic tapes are used in sand bags.[14]

26. Workman, C. E., US Patent 3,772,136, 13 November 1973, assigned to General Mills, Inc.

27. Port, M. I. and Schwartz, B. L., US Patent 3,503,106, 31 March 1970, assigned to Patchogue Plymouth Co.

CONCLUSIONS

a. There is a growing potential for replacement of some woven and knitted fabrics with a new generation of nonwoven fibrous structures. These include webs commercially described as spunbonded, spunlaced, meltblown, stitchbonded fibers and stitchbonded yarns.

b. The overall future for microporous film and microporous or macroporous foams is less certain. However, such materials might be used to a greater extent in composite sheets which replace textiles or leather.

c. Some replacement applications for new materials might be on a first choice basis where superior performance can be achieved at a lower cost. Others might be on a second choice basis where the material is less satisfactory, but alternates are necessary due to conventional textile shortages under industrial mobilization conditions.

d. The most attractive features of some nonwoven fabrics are integral processes which start with the extrusion of thermoplastic polymers and avoid the need for intermediate batching and transport. Some webs can be made directly from extruded fibers such as in the spunbonded, sprayspun and meltblown processes. Others can be made from fibrous networks developed from extruded film and foam.

e. The following potential applications for novel porous sheet materials appear to merit further investigation:

(1) Thermal Insulation in Cold Weather Clothing and Sleeping Bags - Meltblown web of fine fibers.

(2) Duck and Webbing Substitutes - All categories of porous nonwoven webs containing fibers such as:

(a) Basic nonwoven fabric sheets, especially spunbonded type.

(b) Impregnated nonwoven fabric sheets.

(c) Microporous coated nonwoven fabric sheets.

(d) Various composite sheets containing fibers such as laminates of lighter weight woven or knit fabrics with nonwovens and possibly paper.

(3) Apparel Fabrics - Stitchbonded yarns.

(4) Warm Outerwear Fabrics and Blankets - Stitchbonded staple fibers.

(5) Edible Disposable Fabrics - Spunbonded web from fibers of soy protein isolate.

(6) Nonwoven Fabric Garments and Components - Wet lay processes for staple fibers and wet binders using either principle of electrophoresis on an electrode form or principle of water diffusion into a porous form. Also, spray processes using staple fibers and dry or wet binders applied to a form.

(7) Sandbags - Continuous tube of sprayspun nonwoven fabric which is cut and sealed.

(8) Synthetic Leather Gloves - Formation of a microporous foam sheet on a glove form.

(9) Novel Nonwoven Fibrous Sheet - Polymerization of a monomer in a frozen solvent matrix by exposure to ionizing irradiation. Includes webs shaped in the form of a garment or garment component.

f. Considerable materials research and development and fabricated end item testing will be required to fully evaluate and adapt the new porous sheets for specific military applications. In most cases, such progress will be dependent on currently active industry programs and future close cooperation between industry proponents and US Army Natick Development Center. Possible exceptions involving predominantly US Army Natick Development Center initiative and activity would be:

(1) The electrophoretic process for nonwoven formed fabrics.

(2) Nonwoven webs made from monomers in frozen solvents polymerized by exposure to ionizing radiation from the US Army Natick Development Center LINAC and Cobalt 60 sources.

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APPENDICES

APPENDIX A

TYPICAL RELATIVE PROPERTIES AND POTENTIAL OF NONWOVEN SHEETS

Process	Polymers	Wt. Range (g/m^2)	Cost	Breaking Strength	Tear Strength	Flexibility	Opacity	Current Uses	Projected Uses
Wet and dry laid staple fibers (and wood pulp)	Viscose, polyester or nylon	---------	Low to moderate	Poor to good	Poor to good	Poor with higher strength	High	Disposables and clothing interlining.	Shelter materials and CW overgarments.
Spunbonded (pointbonded and area bonded)	Nylon	10 to 102	Low	Good	Good	Fair	Low	Home furnishing and sleeping bag diaphragms.	Parachute canopies, shelter materials and clothing.
	Polyester	14 to 203	Low	Good	Good	Fair	Low	Apparel interlining.	Shelter materials.
	Polypropylene	17 to 136	Low	Fair to good	Good	Fair to excellent	Low	Home furn. and disposables.	Bedding and shelter materials.
	Polyethylene	37 to 102	Low	Fair to good	Fair to good	Fair to good	High	Prntg, book cov. and disposables.	Tags and labels.
Meltblown	Polypropylene or polyester	---------	Low	Poor	Poor	Excellent	High	None	Bedding and clothing insulation.
Spunlaced	Polyester	41 to 81	High	Fair to good	Fair to good	Excellent	Low to high	Home furnishings.	Clothing, body camouflage, bedding, parachute canopies and shelter materials.
Stitchbonded yarns	Variable	---------	High	Good to excellent	Good to excellent	Good	High	Home furnishings and clothing.	Clothing.
Stitchbonded staple fibers	Variable	---------	Moderate	Fair to good	Fair to good	Fair to good	High	Blankets and clothing.	Blankets, clothing, shelter materials and CW overgarments.

APPENDIX B

SPUNBONDED FABRICS MANUFACTURED IN THE UNITED STATES

Manufacturer	Trade Name	Polymer
du Pont	Reemay	Polyester
du Pont	Tyvek	Polyethylene
du Pont	Typar	Polypropylene
Monsanto	Cerex	Nylon
Kimberly Clark	Kimcloth	Polypropylene
Crown Zellerbach	Crowntex	Polypropylene (composite)
Crown Zellerbach	Fibretex	Polypropylene

APPENDIX C

SPUNBONDED NONWOVEN FABRICS CITED FOR COMPONENTS IN END ITEM SPECIFICATIONS

	End Item Specification				
Spunbonded Type	Number	Date	Title	Para.	Component
Nylon (Cerex)	MIL-S-830G (and Amend. 1)	10 Dec 71 and (26 Sep 73)	Sleeping Bags, M-1949	3.3.2	Diaphragm (option)
Nylon (Cerex)	MIL-S-43880	25 Mar 74	Sleeping Bag (Feathers/ Down and Polyester Batting)	3.3.2	Diaphragm
Polyester (Reemay)	MIL-C-43724A	17 Jun 71	Cap, Hot Weather, Olive Green 106	3.2.4	Sweatband interlining and sizing strip
Polyester (Reemay)	MIL-H-43577B	30 Jul 71	Hats, Sun, Hot Weather	3.2.3	Brim interlining and head band stay piece
Polyester (Reemay)	LP/P.DES 40-71	21 Dec 71	Hats, Desert, Combat	3.2.3	Brim interlining and head band stay piece
Polyester (Reemay)	MIL-S-43864	18 Dec 73	Shirt, Woman's Training/ Duty Uniform	3.2.2	Collar interlining
Polyester (Reemay)	LP/P.DES 16-74	08 Aug 74	Shirt, Girls'; Junior ROTC	3.2.2 1/	Collar and cuff interlining
Polyester (Reemay)	MIL-D-43732A	10 Jan 73	Dress Woman's; Hospital Duty Uniform	3.2.2.2	Belt interlining

Note: 1/ Referenced to MIL-C-43836, dated 9 February 1973, for Cloth, Interlining, Non-woven.

APPENDIX D

PERFORMANCE OF MALIMO MACHINES

Malimo Type	Average Production Rate* m/h	Typical Fabric Weights** g/m^2
Malimo	70 to 100	100 to 350
Malipol	60 to 100	200 to 1000
Maliwatt	100 to 200	100 to 500
Voltex	70 to 100	--
Malivlies	70 to 100	280 (for lining fabric)

* These rates apply for the most common stitch lengths. Theoretically 50 to 450 m/h can be produced under various machine speeds and stitch lengths.

** Include a variety of fiber types, yarns and fabric constructions for a closed fabric.